



June 12, 2017

FOUNDATION INVESTIGATION AND DESIGN REPORT

**Highway 401 Structural Culvert
Rehabilitation/Replacement - Site No. 21-494/C
Highway 35/115 and Highway 401
Ministry of Transportation, Ontario
G.W.P. 2242-14-00**

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GEOCRE NO: 30M15-312

Report Number: 1540419-6

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REPORT





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**FOUNDATION REPORT - STRUCTURAL CULVERT
REHABILITATION/REPLACEMENT - HIGHWAY 401
SITE NO. 21-494/C**

PART A

**FOUNDATION INVESTIGATION REPORT
HIGHWAY 401 STRUCTURAL CULVERT REHABILITATION/REPLACEMENT
SITE NO. 21-494/C
HIGHWAY 35/115 AND HIGHWAY 401
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P. 2242-14-00**



1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by D.M. Wills Associates Ltd. (D.M. Wills) on behalf of Ministry of Transportation, Ontario (MTO) to provide Foundation Engineering services for the replacement/rehabilitation of various culverts on Highway 35/115 and Highway 401 in the Region of Durham, Ontario.

The Terms of Reference and the Scope of Work for the foundation investigation are outlined in MTO's Request for Quotation, dated August 2015. Golder's proposal for the Foundation Engineering services associated with the culvert replacement is contained in Section 3.5 of D.M. Wills' Technical Proposal for this assignment. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated December 1, 2016.

This report addresses the investigation carried out for the structural culvert at about STA 22+644 on Highway 401 (MTO Structure Site No. 21-494/C) which has been identified for rehabilitation or potential replacement. The foundation investigation associated with the other culverts, which forms part of the Foundation assignment are presented in separate reports.

2.0 SITE DESCRIPTION

The structural culvert at site No. 21-494/C (Culvert C6) requiring rehabilitation or replacement is located at STA 22+644 on Highway 401, approximately 1950 m east of Newtonville Road in Newtonville, Municipality of Clarington, Ontario as shown on the Key Plan on Drawing 1. The existing culvert is an open footing concrete structure about 74 m long (including a subsequent 4 m long extension to the south) and is about 3.05 m wide and 1.56 m high and is located within an approximately 9.2 m high fill embankment. Details of the existing culvert are also summarized in Table 1 following the text of this report.

In general, the topography in the area of the culvert consists of a relatively flat to gently rolling plain which has been developed for agricultural purposes. Along the water course leading to/from the culvert there are generally densely populated treed areas. The ground surface in the vicinity of the culvert is at about Elevation 121 m and the invert of the culvert is about Elevations 121.5 m and 120.9 m at the inlet (north end) and outlet (south end), respectively. The Highway 401 grade over the culvert is at about Elevation 130.1 m. The existing highway embankment consist of earth fill, up to about 7.3 m high over the culvert at the highway centreline, with side slopes inclined at approximately 2.5 horizontal to 1 vertical (2.5H:1V).

3.0 INVESTIGATION PROCEDURES

The fieldwork for the foundation investigation associated with structural culvert C6 (Site No. 21-494/C) at STA 22+644 was carried out between October 3 and 6 and on December 1, 2016 during which time a total of four boreholes were advanced at, or in the immediate vicinity of the culvert alignment as shown on Drawing 1.

The field investigation was carried out using track-mounted and truck-mounted drilling equipment supplied and operated by a specialist drilling contractor, Atcost Drilling Inc., of Gormley, Ontario. The boreholes were advanced through the overburden using 254 mm outer diameter (O.D.), 108 mm inner diameter (I.D.) hollow stem augers or 125 mm O.D. solid stem augers. Soil samples were obtained at intervals of depth of about 0.75 m and 1.5 m using



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a 50 mm O.D. split-spoon sampler operated by an automatic hammer on the drill rig, performed in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586)¹.

A piezometer was installed in Borehole C6-4 to allow monitoring of the groundwater level at this site. The piezometer consist of a 50 mm diameter PVC pipe, with a slotted screen positioned within the silt till deposit. The borehole and annulus surrounding the piezometer pipe above the screen and sand pack were backfilled with bentonite pellets to ground surface. The piezometer installation details and water level readings are noted on the Record of Borehole C6-4 in Appendix A. All other boreholes were backfilled with bentonite upon completion of drilling in accordance with Ontario Regulation 903 (Wells) (as amended). The groundwater conditions and water levels in the open boreholes were observed during and immediately following the drilling operations and are described on the Record of Borehole sheets in Appendix A.

The fieldwork was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, logged the boreholes, and examined the soil samples. The soil samples were identified in the field, placed in appropriate containers, labelled and transported to our Mississauga geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO Laboratory Standards and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected soil samples. The results of the laboratory testing are summarized on the Record of Borehole sheets in Appendix A and provided on the laboratory test sheets in Appendix B.

A soil sample was obtained during the field investigation at about the culvert invert elevation, using appropriate sampling protocols, and was submitted to a specialist analytical laboratory under chain of custody procedures for chemical analysis of a suite of parameters (corrosivity package) to assess the potential for the soil to cause deterioration of buried concrete or corrosion to steel reinforcing elements. The results of the analytical testing are presented in Appendix C and are summarized in Section 4.3.

The as-drilled borehole locations were measured relative to existing site features and were subsequently converted into MTM NAD 83 coordinates in AutoCAD. The elevation of the boreholes was obtained by plotting the borehole locations on the topographic mapping provided by D.M. Wills on January 20, 2016. The borehole locations given on the Record of Borehole sheets and shown on Drawing 1 are positioned relative to MTM NAD 83 (Zone 10) northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum. The borehole locations (including geographic coordinates), ground surface elevations and drilled depths are as follows:

¹ ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils, ASTM International, West Conshohocken, PA, 2011



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Borehole	Location (m)		Ground Surface Elevation (m)	Depth of Borehole (m)
	Northing	Easting		
C6-1	4866801.7 (43.936526)	387804.4 (-78.466115)	125.6	13.8
C6-2	4866792.6 (43.936431)	387845.2 (-78.465606)	130.0	19.9
C6-3	4866757.4 (43.936124)	387833.9 (-78.465756)	130.0	20.0
C6-4	4866739.4 (43.935959)	387857.0 (-78.465471)	121.9	10.8

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

This section of Highway 401 is located within the Iroquois Plain physiographic region, as delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, 1984)² and *Urban Geology of Canadian Cities* (Karrow and White, 1998)³. The Iroquois Plain extends around the western shores of Lake Ontario. The Plain is comprised of the flat to undulating lakebed and beaches of the former glacial Lake Iroquois, which occupied this area during the last glacial recession.

The surficial soils in this area of the Iroquois Plain are typically comprised of glaciolacustrine clays, silts and sands to gravelly sands, which are underlain by an extensive till deposit that is mapped in this area as the Bowmanville Till.

4.2 General Overview of Local Subsurface Conditions

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced during this investigation, together with the results of the laboratory tests carried out on selected soil samples, are presented on the Record of Borehole sheets and the laboratory test sheets in Appendices A and B, respectively. The stratigraphic boundaries shown on the Record of Boreholes sheets are inferred from non-continuous sampling, observations of drilling progress and in situ testing and are approximate. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

The stratigraphy at the borehole locations at the culvert site generally consists of surficial layers of non-cohesive fill underlain by a silt deposit. The fill and granular deposits are generally underlain by a non-cohesive till deposit which is in turn underlain by a cohesive till deposit in places. A detailed description of the subsurface conditions at the culvert crossing is provided in the following section of this report. Where relatively significant thicknesses of overburden units were encountered, the various soil types are described in detail for each main deposit or stratum.

² Chapman, L.J., and Putnam, D.F., 1984. *The Physiography of Southern Ontario*, 3rd Edition. Ontario Geological Survey, Special Volume 2. Ontario Ministry of Natural Resources.

³ Karrow, P. F., and White, O. L., 1998. *Urban Geology of Canadian Cities*. Geological Association of Canada Special Paper No. 42. St. John's, Nfld.



4.2.1 Asphalt and Road Base

Boreholes C6-2 and C6-3 were advanced through the existing Highway 401 roadway and penetrated an asphalt layer approximately 500 mm and 200 mm thick, respectively. The uppermost layer of road base material underlying the asphalt consists of sand and gravel and is 0.8 m and 0.6 m thick at the respective boreholes. The SPT 'N'-values measured in this layer are 60 blows for 0.3 m of penetration and 50 blows for 0.18 m of penetration, indicating a very dense relative density.

4.2.2 Topsoil

A 100 mm thick layer of topsoil was encountered at ground surface in Borehole C6-4.

4.2.3 Embankment Fill

Embankment fill, approximately 0.6 m to 7.9 m thick was encountered in all boreholes immediately below existing ground surface and underlying the topsoil or road base layer (where present). The embankment fill consists of sandy silt to silt and sand to sand and gravel. In Borehole C6-4 an upper 0.6 m thick layer of cohesive fill consisting of clayey silt, some sand, trace organics was encountered underlying the topsoil. Trace organics was also encountered throughout the non-cohesive fill deposit. Grinding of the augers was observed throughout the embankment fill deposit in all of the boreholes advanced at this site, suggesting the potential presence of cobbles; boulders and/or debris from abandoned temporary works associated with the original culvert construction may also be present buried within the fill and, and based on findings from other culvert sites, may consist of logs, stumps, and brush from the clearing and grubbing operations.

The SPT 'N'-values measured within the non-cohesive embankment fill deposit range between 13 blows and 58 blows per 0.3 m of penetration, indicating a generally compact to very dense relative density, with one 'N'-value of 3 blows per 0.3 m of penetration immediately below the cohesive fill, indicating a loose relative density. One SPT 'N'-value measured in the non-cohesive embankment fill deposit is 3 blows per 0.3 m of penetration, suggesting a soft consistency.

The natural water content measured on seven samples of the non-cohesive embankment fill ranges between about 8 per cent and 17 per cent.

The results of grain size distribution tests completed on six samples of the sandy silt to silt and sand fill are shown on Figure B1 in Appendix B.

4.2.4 Silt

A 0.5 m to 2.8 m thick deposit of silt was encountered in Boreholes C6-2, C6-3 and C6-4 underlying the embankment fill, between Elevations 122.1 m and 120.1 m. Trace organics was encountered throughout the silt deposit in Borehole C6-2 and an organics content test measured 6.5 per cent organics on one sample of the deposit.

The SPT 'N'-values measured within the silt deposit range between 13 blows and 105 blows per 0.3 m of penetration, and 50 blows for 0.1 m of penetration at one sampling depth, indicating a compact to very dense relative density.

The natural water content measured on four samples of the silt deposit are between about 6 per cent and 16 per cent.



The results of grain size distribution tests completed on two samples of the silt deposit are shown on Figure B2 in Appendix B.

An Atterberg Limits test carried out on a sample of the silt deposit indicates that the material is non-plastic.

4.2.5 Silt to Silt and Sand Till

A till deposit comprised of silt to sandy silt to silt and sand, trace to some gravel, was encountered in all of the boreholes advanced at this site between depths of about 2.1 m and 11.5 m below ground surface, at between Elevations 123.5 m and 117.9 m, respectively, and the thickness of the deposit ranges between 6.8 m and 11.5 m but the deposit was not fully penetrated in Boreholes C6-2 to C6-4. Grinding of the augers was observed throughout the silt to silt and sand till deposit in some of the boreholes, suggesting the potential presence of cobbles and/or boulders.

The SPT 'N'-values measured within the silt to sandy silt till deposit range from 72 blows per 0.3 m of penetration to greater than 50 blows for 0.15 m of penetration, indicating a very dense relative density.

The natural water content measured on thirteen samples of this non-cohesive till deposit range between about 7 per cent and 15 per cent.

The results of grain size distribution tests completed on eight samples of the silt to sandy silt till deposit are shown on Figures B3 and B4 in Appendix B.

Atterberg limits tests carried out on two samples of the silt and sandy silt strata of the till deposit measured liquid limits of about 17 per cent and 13 per cent, plastic limits of about 15 per cent and 11 per cent and plasticity indices of about 2 per cent. These results, which are plotted on the plasticity chart on Figure B5, indicate that the fines of the till deposit are comprised of silt of slight plasticity.

4.2.6 Clayey Silt Till

A cohesive till deposit consisting of clayey silt, trace gravel was encountered in Borehole C6-1 underlying the silt and sand till deposit at a depths of 11.4 m below ground surface, corresponding to Elevation 114.2 m, and the deposit is 2.4 m thick but was not fully penetrated.

The SPT 'N'-values measured within the clayey silt till deposit are greater than 50 blows for 0.13 m of penetration, suggesting a hard consistency.

The natural water content measured on a sample of the clayey silt till is 11 per cent.

An Atterberg limits test carried out on one sample of the cohesive till deposit measured a liquid limit of about 17 per cent, a plastic limit of about 11 per cent and a plasticity index of about 6 per cent. The test result, which is plotted on the plasticity chart on Figure B6 in Appendix B, indicates that the material tested is a clayey silt of low plasticity.

4.2.7 Groundwater Conditions

The water level was measured in Borehole C6-1 and C6-2 upon completion of drilling operations at depths of 5.2 m and 10.7 below ground surface, corresponding to Elevations 120.4 m and 119.3 m.

A piezometer was installed in Borehole C6-4 on the south side of Highway 401 and the observed groundwater level is shown on the Record of Borehole sheet and summarized below.



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Borehole	Depth to Water Level (m)	Groundwater Elevation (m)	Date of Measurement
C6-4	3.6	118.3	October 4, 2016
	-0.1	122.0	March 28, 2017

The water level observed in the boreholes during and/or upon completion of drilling may not represent the longer-term, stabilized groundwater level at the site. The water level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

4.3 Analytical Testing of Soil Sample

Analytical testing was carried out on a composite soil sample constituted from the SPT samples recovered from near the culvert invert elevation at Borehole C6-3. The analytical parameters include conductivity / resistivity, pH sulphate and chloride to allow for the assessment of the potential for the soil to cause deterioration of concrete and corrosion of steel. The laboratory test results are included in Appendix C and are summarized below.

Parameter	Test Result
Soil Resistivity	1200 ohm-cm
Soil Conductivity	824 umho/cm
Sulphate Concentration	23 ug/g
Chloride Concentration	450 ug/g
PH	7.95

5.0 CLOSURE

Ms. Amelia Jewison, supervised the borehole investigation program. This report was prepared by Mr. Matthew Kelly, P.Eng., a geotechnical engineer with Golder. Mr. Jorge Costa, P.Eng., a Senior Consultant with Golder and Designated MTO Foundations Contact conducted an independent quality control review of this report.



Report Signature Page

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PART B

**FOUNDATION DESIGN REPORT
HIGHWAY 401 STRUCTURAL CULVERT REHABILITATION/REPLACEMENT
SITE NO. 21-494/C
HIGHWAY 35/115 AND HIGHWAY 401
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P. 2242-14-00**



6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

This section of the report provides foundation design recommendations for structural culvert C6, Site No. 21-494/C located at about STA 22+644 on Highway 401, approximately 1,950 m east of Newtonville Road in the Municipality of Clarington, Ontario. The existing structure, including a previously constructed 4 m long extension to the south, is about 73.5 m long. It is an open footing concrete culvert which is 3.05 m wide and 1.53 m high. The current design based on direction provided at the 60% executive review meeting requires only rehabilitation of the existing culvert (i.e. there is no new replacement culvert, headwalls/wing walls or culvert extensions planned). Although foundation design recommendations are not required for the proposed rehabilitation, MTO's Foundation Section requested preliminary recommendations for feasible trenchless installation methods for this site for a new or replacement culvert in the future.

These recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the investigation. The discussion and recommendations presented for the design of a trenchless crossing are preliminary and are intended to provide the designer with sufficient information to assess the feasible design alternatives only. The Foundation Investigation Report, discussion and recommendations are intended for the use of the Ministry of Transportation, Ontario (MTO) and shall not be used or relied upon for any other purpose or by any other parties, including the construction or design-build contractor. The contractor must make their own interpretation based on the factual data in Part A (Foundation Investigation) of the report. Additional recommendations will be required to carry out the detailed design of any new culvert(s), if required, once invert elevations, alignments and culvert sizes are known. Where comments are made on construction, they are provided in order to highlight those aspects that could affect the design of the project and for which special provisions may be required in the Contract Documents. Those requiring information on the aspects of construction should make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

6.1 Consequence and Site Understanding Classification

In accordance with Section 6.5 of the Canadian Highway Bridge Design Code (CHBDC 2014) and its Commentary, a classification of 'typical' consequence has been assumed for a replacement culvert section and foundation system. This consequence classification should be confirmed by the MTO.

The degree of site understanding based on the scope of the foundation investigation and proximity of the boreholes to the culvert is considered 'typical' as described in Clause 6.5.3.2 of the 2014 CHBDC. The appropriate Ultimate Limit States (ULS) and Serviceability Limit States (SLS) consequence factor, Ψ , and the geotechnical resistance factors at ULS (ϕ_{gu}) and SLS (ϕ_{gs}), respectively from Tables 6.1 and 6.2 of the CHBDC (2014) have been used for design.

6.2 Design Assumptions – Trenchless Replacement

It is anticipated that a replacement culvert at Site No. 21-494/C would likely be installed adjacent to and at a vertical profile at the existing culvert at approximate invert Elevations 121.5 m and 120.9 m at the inlet and outlet ends, respectively. Assuming that the existing open footing culvert is representative of the minimum size required to convey the design flows and satisfy hydraulic requirements, a replacement culvert would be expected to have an equivalent diameter of about 2.5 m. For the purposes of a trenchless installation assessment, it has been assumed that the maximum diameter of a replacement culvert would be about 3.0 m to satisfy hydraulic design. Based on these assumptions, the depth/thickness of cover relative to the existing Highway 401 pavement surface is expected to range from about 6.7 m to 7.2 m over the culvert obvert.



If space and hydraulic requirements permit, the new or relief culvert should be installed no closer than 1 m from the wall of the existing culvert, however a separation distance of 2 tunnel diameters is preferred/recommended.

6.3 Anticipated Ground Conditions

Progressing from north to south, the subsurface conditions encountered along the proposed culvert vertical alignment generally consists of very dense silt and sand glacial till at the inlet end changing near the north shoulder of the Highway 401 westbound lanes to a mixed face condition comprised of compact to dense granular fill and compact to very dense silt in turn underlain by a very dense deposit of silt to silt and sand glacial till. Granular embankment fill and native silt to silt and sand till/silt deposits are anticipated to occupy a majority of the face of the tunnel alignment. The embankment fill within the tunnel excavation face will be comprised of sand zones and clayey silt zones near the outlet end. The presence of cobbles and boulders within the embankment fill and glacial till deposits has been inferred from auger resistance/grinding encountered in Boreholes C6-1, C6-3 and C6-4. Our recent experience with trenchless crossings of major MTO highways suggests that there may be debris consisting of abandoned temporary works associated with the original culvert construction. This debris may be buried in the fill, or present at the interface between the embankment fill and native soil. It may consist of logs, stumps, and brush from the clearing and grubbing operations. Generally, the groundwater level along the tunnel profile is anticipated to be near or slightly above the culvert invert, at about Elevation 121.5 m. During construction, groundwater may be encountered perched in the granular fill layers overlying the lower permeability native deposits.

The anticipated behavior of the anticipated subsurface materials can be classified using Terzaghi's Tunnelman's Ground Classification system as modified by Heuer (1974). The behaviour of the materials within the tunnel alignment is summarized as follows.

Material	Tunnelman's Ground Classification	
	Above Groundwater Level	Below Groundwater Level
Non-Cohesive (sandy silt to silt and sand) Fill	Cohesive running to slow raveling	Flowing
Cohesive (clayey silt) Fill	Firm	Firm
Silt	Cohesive running	Flowing
Glacial Till (silt to sandy silt to silt and sand)	Firm to slow raveling	Firm to fast raveling

In the absence of dewatering, the fills and native granular soils, if saturated, will collapse and flow in an unsupported excavation. The cohesive fill deposits would have a stand-up time ranging from a few minutes to several hours depending on the degree of seepage, disturbance and localized gradation of the deposits. The stand-up time of this material will likely be unpredictable.

Trenchless installations will be primarily affected by five factors associated with the subsurface and groundwater conditions, namely:



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- The nature of the embankment fill: the embankment fill is granular in composition and can be excavated using several trenchless methods provided that the appropriate precautions are taken to preserve face stability, prevent void formation and potential loss of ground.
- Buried obstructions: Cobbles and/or boulders are inferred to be present within the fill based on auger resistance and grinding encountered when advancing the boreholes. Our recent experience with trenchless crossings of major MTO highways suggests that there may be debris consisting of abandoned temporary works associated with the original construction; such as logs, stumps and brush from the clearing and grubbing operations; and cobbles and boulders buried in the fill. Such obstructions have the potential to damage/clog/obstruct machinery and halt trenchless operations, particularly if there is no person-access to the excavation face to clear the obstruction.
- Mixed Face Tunnelling: Depending on the selected invert elevation, the excavation face will encounter a mixed face consisting of generally compact non-cohesive fill and very dense native soils including silt and silt to sandy silt glacial till containing cobbles and boulders. In addition to the potential for encountering obstructions buried in the fill, the selected trenchless methodology must be adaptable to the above-noted subsurface conditions which can vary both longitudinally along the bore alignment and horizontally and vertically across the face. Differences in jacking loads across the face should be expected. In general, the native materials near the invert are denser than the overlying fill. When tunnelling in these conditions, it may be difficult to maintain line and grade. To improve accuracy, it may be necessary to advance the tunnelling operation at a slow rate to be able to properly excavate the denser materials at the face. There is the potential for the casing/pipe to ride-up on the more resistant materials near the invert and into the looser/softer overlying fills.
- Presence of cobbles and boulders: Cobbles and boulders should be anticipated in the fill and glacial till deposits as inferred present by auger grinding in some boreholes. The advance of microtunneling and conventional tunnel boring machines (TBM)s can be hindered, or even fully obstructed by cobble nests or boulders. The assumed diameter of the new/replacement culvert at this site is such that person entry for removal of obstructions is possible depending on the selected means and methods of tunnelling.
- Groundwater at the invert level: the groundwater condition at this site is favourable to trenchless installation methods since it permits a wider range of trenchless methodologies to be used. However, those that do not provide effective face support against ravelling granular materials or flowing granular fill should be prohibited.

6.4 Review of Trenchless Construction Methods

Several methodologies have been considered for executing this crossing: horizontal auger boring (jacking-and-boring), pipe ramming, microtunnelling, hand mining or mechanically-assisted excavation within a shield with jacked pipe or steel liner plate or steel ribs and lagging, conventional tunneling with a TBM, and utility tunnelling.

6.4.1 Jack-and-Bore

Jack-and-bore involves forming a horizontal borehole through the ground from a drive shaft to an exit shaft by means of a rotating cutting head. The cutting head is attached to continuous-flight helical augers within a casing which transports spoils from the face to the drive shaft. Jack-and-bore installations in mixed face conditions within looser fill soil deposits overlying denser native soil deposits containing cobbles and /or boulders are risky since



the casing is highly susceptible to being deflected or impeded by the obstructions. The availability of contractors with the equipment and experience to complete a jack-and-bore installation with a diameter greater than 1.8 m is quite limited. Considering the subsurface conditions and diameter ranges that may be selected for a replacement culvert, jack-and-bore is not considered a feasible option.

6.4.2 Pipe Ramming

Pipe ramming involves the use of a steel casing, inserted from a launch pit, and driven by a pneumatic percussion hammer or a hydraulic jacking system. The leading edge or head of the initial steel casing is fitted with a cutting shoe/band to reinforce the pipe for open-face pipe ramming and reduce friction by creating a slight overcut. As the casing advances towards the exit pit, additional lengths of steel casing are welded on to the preceding piece. Bentonite or polymer lubricants may be used to facilitate advancement of the casing where the soil conditions dictate. The material within the casing is removed by augering after the casing is installed. The accuracy of the line and grade are comparable to the jack-and-bore method.

Compared to hand mining, conventional tunnelling with a TBM or microtunnelling, pipe ramming is more susceptible to deflection if the pipe is being driven along an interface with materials of differing densities. There are very few pipe ramming contractors in Ontario capable of completing a large-scale ramming installation (for pipes greater than 2.0 m in diameter) or that can overcome the frictional forces for pipe alignments longer than about 75 m. Given the subsurface conditions and the assumed length and diameter of the culvert, use of pipe ramming is considered unsuitable for this site.

6.4.3 Microtunnelling

Microtunnelling is a guided pipejacking process which uses a remotely controlled tunnelling machine to provide continuous support to the excavation face. It relies on a horizontal jacking force applied to the pipe to propel the remotely controlled microtunnel boring machine (MTBM) along with the pipe string through the ground. The pipe is typically installed while the bore is being advanced and serves both as temporary ground support and the final culvert. Specially designed jacking pipe made from steel, glass fibre reinforced plastic (GFRP) or reinforced concrete, and capable of transferring the jacking forces from the jacking reaction frame in the shaft to the MTBM, will be required. Entry and receiving shafts are required for microtunnelling operations. Dewatering will be required only at the shafts since most MTBMs can operate in saturated soils below the groundwater level. Microtunnelling is typically able to maintain high accuracy ($\pm 25\text{mm}$) with line and grade control.

A slurry MTBM has a full-face rotating cutting head with openings through which the spoil enters a pressurized slurry chamber behind the head. The slurry is used to balance the hydrostatic pressure and convey suspended cuttings away from the face. Typically, MTBMs are ill-equipped for crushing or cutting boulders once they enter the machine even though some models have a crusher chamber which breaks down obstructions to a size which can be pumped with the cuttings. However, the volume, diameter or numbers of the cobbles and boulders may be such that the capacity of the crusher could be exceeded resulting in either abandonment of the bore or advancement of a rescue shaft to remove the obstructions and permit resumption of tunnelling. If woody debris is encountered in the fill, it will likely clog the machine, also necessitating a rescue shaft and possibly repairs.

The MTBM should be equipped for mixed face conditions. The selected cutting tools and methods should be compatible with variable ground conditions, including cobbles and boulders. Properly selected rock disc cutter should be used to cut the glacial tills and break cobbles and boulders at the face into smaller enough fragments to pass through the apertures in the face. Only closed-face machines equipped with rock disc cutters in



combination with soft ground excavation tools on the MTBM face, relatively small face openings and an internal crusher chamber should be used at this site. In addition to cobbles and boulders, the Contractor's work plan should include a method of dealing with debris in the fill materials.

An overcut will be required to reduce frictional forces along the pipe string, reduce jacking forces, and facilitate steering. The annulus between the outside of the pipe and ground should be immediately filled with bentonite slurry of an appropriate viscosity from flow from the MTBM face and around the MTBM ports in the tail of the MTBM and/or lubrication ports in the pipes installed at regular intervals.

The fill deposits along the tunnel alignment are generally less dense than the native deposits at or below the culvert invert. Noting that the embankment fill and glacial till contain cobbles and boulders, the Contractor should be prepared for steering difficulties, deflection of the machine and increased wear or damage to the cutters or cutter housings due to high impact forces.

Person-entry to remove obstructions is generally not available for most MTBMs. Even if equipped with a crusher chamber and rock cutting tools, the MTBM will likely be stopped by boulders greater than one third of the diameter of the tunnel. Given the potential for encountering obstructions in the embankment fill and native till deposits, there is a high to very high risk of these obstructions either impeding or halting the machine. The practical pipe size that can be installed using microtunnelling ranges from 1.2 m to 4.2 m. although most Ontario contractors have equipment capable of installing pipes up to a maximum of 2.1 m. For these reasons, a microtunnelling installation at this site is considered to be only marginally feasible and may be impractical, depending on the casing diameter.

6.4.4 Hand or Mechanically-Assisted Mining

Hand mining or mechanically assisted excavation, within a shield with jacked pipe, steel liner plate, or steel ribs and lagging, is considered a feasible method for the culvert installation provided groundwater pressures and seepage are adequately controlled. The applicable range of pipe diameters is limited only by cost and availability of labour. However a minimum diameter of 1.2 m is required for person-entry, which is the case for the culvert proposed for this site. In this method, the tunnelling process is carried out by removing excavated soil from the front cutting face and installing a liner to form a continuous ground support structure. The liner may be installed using a two-pass system or a single pass where the culvert pipe is jacked into place during excavation and provides both temporary and permanent support. With a two-pass system, a segmental temporary or primary liner is installed from the entry to the exit shaft followed by a permanent or secondary liner. The primary liner may consist of steel ribs and wooden lagging or steel liner plates. The secondary liner is typically of cast-in-place concrete construction but may be a smaller primary conduit (carrier) pipe of any suitable material. If the carrier pipe option is used, the annulus between the conduit (carrier) pipe and the primary liner is grouted. The soil may be excavated using hand mining techniques and shields that include the capability of closing the face with breasting boards, plates or mechanical systems. The most economical option would be to install the culvert in a single pass using a steel pipe. Higher costs would be incurred for concrete pipes and two-pass systems.

In hand mining, excavation is conducted at the face using picks, shovels, or pneumatic hand held tools. Using conventional tunnelling or pipe jacking techniques, a protective shield, which may have a forward hood projection to provide additional face stability during soil excavation is usually required. If an articulated shield is used, line and grade corrections can be accomplished by activating the hydraulic propulsion cylinders. In a fixed shield, minor line and grade changes are accomplished by differential excavation in the desired direction.

Mechanically-assisted excavation is accomplished by using special shields equipped with power excavation devices. Such soil cutting devices can be rotary cutter booms mounted on the front of the shield, modified hydraulic



backhoes, or rotary boom cutters. The soil excavation rate of open-face mechanical excavation is much faster than that of hand mining. Mechanical assistance is normally required for pipe diameters of 2.1 m or greater.

Dewatering at the entry and receiving shafts will likely be required. Since the groundwater level will likely be between the invert and the springline, dewatering of the non-cohesive fills and native materials with horizontal vacuum drainage lances/pipes from the tunnel face will be required.

The Contractor's selected equipment and methods must provide effective control of the stability of the face soils which are prone to raveling or cohesive running if properly dewatered. Fore-poling or spiles driven into the ground ahead of the face will be necessary to prevent loss of ground and improve support for the tunnel crown. Use of a hooded shield where the top of the shield extends beyond the invert by providing an angled profile to the leading edge of about 60 degrees from the horizontal is recommended. This angle must be measured from the top of the shield to the invert. The shield should have doors which can close off the entire face and retractable breast plates or horizontal bench plates when additional support of the face is necessary, such as in zones with loose materials.

Overexcavation can lead to ground losses particularly where the granular fills extend from the obvert to the pavement. The overcut should be limited to a maximum of 15 mm. It is important that care be taken with the installation of the liner to minimize settlements.

The soil deposits along the proposed alignment are variable in gradation and consistency/relative density. In addition, the alignment will proceed along the interfaces between the looser embankment fill and denser native materials. As such, the jacking forces will be variable and high jacking pressures and difficulty maintaining line and grade may be experienced, particularly if cobbles or boulders are encountered. For each separate jack, it will be necessary to use varying hydraulic pressures and travel movements to improve or correct steering.

Lubricants should be used where high jacking pressures are encountered. The use of bentonite based lubricants is recommended due to the predominance of granular and low plasticity cohesive materials. The spacing and number of grout ports should be optimized to result in even distribution of lubricant over the entire length of pipe and facilitate post-installation grouting of the annulus, if necessary.

Face access facilitates removal of cobbles, boulders and obstructions if encountered. The appropriate health and safety precautions associated with confined spaces as outlined in the current Ontario Regulation 213 in the Occupational Health and Safety Act (OSHA) must be observed by the contractor. Hand mining is considered to be feasible at this site only if proper dewatering measures are employed. This method offers the most flexibility to adapt methods of face support and excavation to unforeseen ground conditions.

6.4.5 Conventional Tunnelling with Tunnel Boring Machine

Installation of the culvert using a tunnel boring machine (TBM) is considered a suitable option for almost any pipe diameter. Since the ground conditions at this site require continual support of the face, only closed-face TBMs that provide support to the face to balance hydrostatic and earth pressures should be employed. Dewatering will be required at the entry and receiving shafts.

Depending on the contractor's available equipment and experience, the size of this installation allows for small diameter conventional (person-entry) TBMs to be used. In this case, face control and cuttings transport may be accomplished using "earth pressure balance" (EPB) technologies in which discharge from the chamber is controlled by pressure relieving gates or doors that open at pre-set pressures or loads. Another system uses a screw conveyor to remove materials from the chamber at rates that maintain specified pressures within much of the excavated chamber. Because of the potential for encountering cobbles, boulders and other obstructions, EPB



TBM's that use screw conveyors should be avoided. While older relieving gate EPB systems are not as controlled as screw conveyor systems, the combination of face opening sizes and relieving gate opening size allows for passage of cobbles, boulders and smaller debris without clogging and damaging the machine and, providing flowing ground is controlled, can allow access to the face to remove larger obstructions. Some TBM systems are promoted as being "earth pressure balance" when they do not actually achieve the goals of the EPB technology. Such unacceptable systems rely only on doors that close the face or rely on jacking forces being transmitted to the steel sections of the machine face where this is then interpreted as "face pressure." Such systems should be prohibited for this project since they could result in significant ground losses and the consequential safety risks and claims. Also, older TBM's that do not include a secondary bulkhead and controlled muck discharge system should be prohibited for this project.

The machine must be equipped with hardened disc cutters (as well as soft ground spade, drag bits and picks) to handle the fill and native soils containing cobbles and boulders. The selected equipment, face tooling and methods must be able to adapt to changing ground conditions which include the presence of flowing, running or ravelling granular materials. The contractor should be prepared to deal with obstructions in the embankment fill and glacial till deposits.

Face stability should be constantly monitored. Overexcavation above or ahead of the TBM and lining should be avoided to maintain face stability. The overcut should be minimized by selection of a lining diameter which is similar to that of the TBM. Face pressure should be selected and maintained at values no less than the active earth pressure at the tunnel vertical centreline. If over excavation or ground losses occur, the annulus between the outside of the pipe and the ground and any voids at the face should be immediately filled with bentonite slurry of an appropriate viscosity and/or low strength grout.

Maintenance of line and grade and advancement of the TBM will be very challenging due to the mixed face condition presents the greatest risk to successful completion of a TBM installation.

6.5 Comparison of Tunneling Methods

Trenchless construction methods described in Section 6.4 include various advantages and disadvantages depending on soil conditions, depth of cover, vertical and horizontal alignment, length of pipe installation, cost and availability of equipment, and carry varying levels of risk of successfully completing the installation. The advantages, disadvantages and relative costs and risks are compared in Table 2, following the text of this report.

Should trenchless replacement of the existing culvert be considered in the future, a cost-benefit analysis should be carried out comparing open cut installation to the trenchless options discussed in this report. To aid in decision making, the feasible options (microtunnelling, hand or mechanically-assisted mining and conventional tunnelling with a TBM) have been ranked in order of decreasing suitability. Methods which are highly adaptable to changing subsurface conditions, at the invert/face and had the potential to provide effective face support were ranked higher. The ranking of the technically feasible trenchless construction methods for this site is as follows:

1. Hand or Mechanically-Assisted Mining
2. Conventional Tunnelling with a TBM
3. Microtunnelling



6.6 Detailed Design of Future Trenchless Replacements

If future trenchless replacement of the existing structural culvert at this site is to be considered, the preliminary recommendations provided in this report should be reviewed. The foundation investigation carried out for this report is considered adequate for detailed design of a trenchless crossing, however it may be necessary to advance test pits or shallow boreholes at the shaft locations for design of the temporary shoring and reaction wall/frames required for jacking of pipe and microtunnelling operations, particularly if multiple culverts are proposed or the new alignments will be offset some distance from the existing boreholes. Additional boreholes may also be warranted if new permanent retaining walls are to be constructed at the site. The detailed design report for trenchless replacement should include discussions and recommendations on:

- Dewatering and groundwater control;
- Suitable trenchless alternatives;
- Face stability and tunnel support;
- Alignment control;
- Estimated settlement/heave and settlement mitigation;
- Settlement monitoring program; and
- Exit/entry shaft and roadway protection.

As has been carried out for other components of this assignment, the Foundations Engineer, design consultant and MTO (including the Foundations Section) should discuss requirements for either a Geotechnical Baseline Report (GBR) or a Subsurface Condition Baseline Report (SCBR), to provide a contractual baseline for allocation of risks. The GBR should be prepared in accordance with the guidelines prepared by the American Society of Civil Engineers.⁴ A SCBR will only present baseline soil and groundwater conditions and a description of the anticipated behaviour of the subsurface soils during installation of the trenchless culvert(s). Unlike a GBR, discussion of the anticipated ground response to the specific construction means and methods will not be included in a SCBR.

6.7 Groundwater Control

It is understood that retrofit wall drains are proposed to be installed along the existing culvert walls as part of the culvert rehabilitation. Measured groundwater levels at this culvert site were at or below the culvert invert level and as such would be below the elevation of the proposed retrofit wall drains. The existing embankment fill consists of relatively free draining sands and silts. Thus, it is anticipated that there is a low potential for continuous seepage / flow through the wall drains. However, it is recommended that the wall drains be adequately filtered to limit the potential for migration of fine soil particles if surrounding groundwater or surface water levels inside the culvert rise to the wall drain level.

6.8 Corrosion Assessment and Protection

Soil corrosivity may affect concrete pipes and headwalls, steel pipes and reinforced steel and other concrete or steel elements buried in the soil. The long-term performance and durability of the structures are directly related to their respective corrosion resistance. Generally, the corrosivity of a structure depends on the soil resistivity,

⁴ Essex, R.J. (ed) (2007). Geotechnical Baseline Reports For Construction, Suggested Guidelines. ASCE, Reston, VA.



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hydrogen ion concentration, salts (chloride and sulphate) concentrations and redox potential. The analytical results for a single composite soil sample are presented in Section 4.3 and are included in Appendix C.

The analytical test results were compared to CSA Standard, CAN/CSA-A23.1-14 Table 3 ("*Additional requirements for concrete subjected to sulphate attack*") for potential sulphate attack on concrete. The sulphate concentration measured in the soil sample tested is less than 0.1 per cent, which is below the exposure class of S-3 (Moderate). Therefore, based on the test results of the single composite sample of existing fill and native soils, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the existing fill and native deposits around the culvert may not need to be considered separately.

The soil has a pH of 7.95 and a resistivity of 1,200 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. However, the resistivity is less than 2,000 ohm-cm, which indicates that the soil corrosiveness is severe ($R < 2,000$ ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). Based on these results some level of pipe protection will be required depending on the type of material chosen for this culvert.

Based on the results of the sample tested, and given that the culvert is located under the roadway shoulder and will be exposed to de-icing salt, consideration should be given by the designer to designing for a "C" type exposure class as defined by CSA A23.1, Table 1.

It is ultimately up to the designer to determine the appropriate exposure class and to ensure that all aspects of CSA A23.1 Section 4.1.1 "Durability Requirements" are followed.

7.0 CLOSURE

This Foundation Design Report was prepared by Mr. Matthew Kelly, P.Eng., a member of Golder's geotechnical engineering staff. The technical aspects were reviewed by Ms. Dirka U. Prout, P.Eng., a senior geotechnical engineer. Mr. Jorge M. A. Costa, P.Eng., a Senior Consultant of Golder and Designated MTO Foundations Contact conducted an independent quality control review of this report.



Report Signature Page

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Heuer, R. E. (1974). "Important Ground Parameters in Soft Ground Tunneling." *Proceedings Specialty Conference on subsurface Explorations for Underground Excavations and Heavy Construction*, ASCE, Reston, VA., p.152-167.

Canadian Standards Association (CSA), 2014. Canadian Highway Bridge Design Code and Commentary on CAN/CSA S6-14. CSA Special Publication, S6.1-14.

Canadian Standards Association (CSA), 2014. Concrete Materials and Methods of Construction. CSA Group Publication, CAN/CSA-A23.1-14.

Karrow, P. F., and White, O. L., 1998. Urban Geology of Canadian Cities. Geological Association of Canada Special Paper No. 42. St. John's, Nfld.

Ontario Ministry of Transportation, 2014. MTO Gravity Pipe Design Guidelines: circular culverts and storm sewers, St. Catharines, Ontario

Ontario Occupational Health and Safety Act:

Ontario Regulation 213/91 Construction Projects as amended by O. Reg. 443/09

Ontario Water Resources Act:

Ontario Regulation 372/9 Amendment to Ontario Regulation 903

ASTM

ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils, ASTM International, West Conshohocken, PA, 2011



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SITE NO. 21-494/C**

TABLES



**FOUNDATION REPORT - STRUCTURAL CULVERT REHABILITATION/REPLACEMENT - HIGHWAY
401
SITE NO. 21-494/C**

Table 1: Summary of Existing Culvert Details

Culvert Location (Municipality)	Culvert ID / Site No.	Approximate Height of Embankment	Existing Culvert			Approximate Invert Elevation ²		Boreholes
			Type	Approximate Dimension	Approximate Length	Inlet (North End)	Outlet (South End)	
STA 22+644 (Clarington)	C6 / 21-494/C	Up to about 9.2m	Open Footing	3.05 m wide x 1.56 m high	73.5 m	121.5 m	120.9 m	4 Boreholes (C6-1 to C6-4)

- Notes:
1. Embankment height is relative to existing ground surface level at the toe of embankment adjacent to the culvert based on drawings provided by D.M. Wills dated August 22, 2016
 2. Culvert invert elevations are based on drawings provided by D.M. Wills dated August 22, 2016.



Table 2: Comparison of Trenchless Techniques for Culvert Replacement

Method	Feasibility	Advantages	Disadvantages	Estimated Relative Cost Factor ^{2, 3}	Risk/Consequence
Jack-and-Bore	Not Feasible	Variable mixed face subsurface conditions (fills, granular deposits, variable relative density of the deposits), length and anticipated diameters preclude use of jack-and-bore.			
Pipe Ramming	Not Feasible	Variable mixed face subsurface conditions (fills, granular deposits, variable relative density of the deposits), length and anticipated diameters preclude use of pipe ramming.			
Microtunnelling	Marginally Feasible	<ul style="list-style-type: none">■ Closed-face machine (slurry MTBM) equipped with rock disc cutters in the face, relatively small face openings and crusher chamber required to deal with cobbles and boulders in the fill and glacial till.■ Dewatering required at the shafts only.■ Fastest rate of advance provided obstructions are not encountered.	<ul style="list-style-type: none">■ Typically the maximum diameter is 3.5 m but Ontario Contractors have equipment capable of installing pipes only up to about 2.1 m diameter.¹■ Even if MTBM is equipped with rock disc cutters and crusher chambers, it will not be able to accommodate oversized boulders (larger than 1/3 the machine diameter) and operations will be halted.■ Wood debris if encountered will likely clog the machine.■ A rescue shaft will be needed to free machine if cobble nests, oversized boulders (>1/3 machine diameter) or woody debris encountered.■ Requires large work area at entry shaft due to the large amount of topside equipment.■ Steering difficulties and slower production may result from differences in material density between top and bottom of face (at interface between looser fill or looser native deposits and denser glacial till) and between each side of the machine; these differences will affect line and grade.	1.5 – 3.5	<ul style="list-style-type: none">■ Encountering woody debris within the fill or native till deposits, or oversized cobble nests or boulders – low to moderate risk of not completing installation.



Table 2: Comparison of Trenchless Techniques for Culvert Replacement

Method	Feasibility	Advantages	Disadvantages	Estimated Relative Cost Factor ^{2, 3}	Risk/Consequence
Hand Mining or Mechanically-Assisted Excavation within shield with jacked pipe, steel liner plate or steel ribs and lagging	Feasible and preferred option (After proper dewatering measures are implemented to lower ground water level to at least the invert level)	<ul style="list-style-type: none">■ Highly adaptable to variable conditions along alignment.■ Face access facilitates removal of cobbles, boulders and obstructions in fill and glacial till.■ Good accuracy for line and grade.■ Most economical solution with line and grade accuracy comparable to microtunnelling.■ Smallest footprint required for entry/exit shaft.■ Potentially the most economical method of installing the culvert at low end of cost range.■ Theoretically no size limitations.	<ul style="list-style-type: none">■ Labour intensive: Due to the presence of granular soils at invert level which may be saturated, the contractor's selected equipment and methods must provide effective control of the stability of the face (e.g., use of hooded shield, stiffeners, forepoling, retractable breast plates with doors etc.).■ Extensive delays may occur removing and breaking up oversized boulders with high strength, if encountered.■ Unlike microtunnelling and conventional tunneling, dewatering by horizontal drainage lances/pipes from start and end shafts will likely be required to control flow in saturated granular soils.■ Slowest rate of advance.■ Cost for tunnel diameters exceeding 2.4 m may approach that of conventional tunneling with TBM or microtunnelling options.	1.0 – 1.8	<ul style="list-style-type: none">■ Encountering woody debris and oversized cobble nests or boulders - low to moderate risk of not completing installation.■ Groundwater at the tunnel invert - moderate risk to high of ground loss due to flowing of sands; risk can be minimized with proper horizontal drainage within tunnel and effective dewatering at shafts
Conventional Tunnelling with Tunnel Boring Machine (TBM)	Marginally Feasible (Closed-face machine must be used to provide effective control of face stability)	<ul style="list-style-type: none">■ Face access possibility can facilitate removal of cobbles, boulders and obstructions in the fill and glacial till.■ High accuracy with line and grade.■ Dewatering required at shafts only if EPB TBM used and can be enhanced with localized use of horizontal drainage lances from entry and exit shafts/pits.■ Compared to hand mining methods, conventional tunnelling may achieve more consistent and effective support of the face.	<ul style="list-style-type: none">■ Older TBMs that do not include a secondary bulkhead and controlled muck discharge system (e.g., discharge gates controlled by load or pressure sensors) should be prohibited.■ Machines can become jammed or clogged with wood and/or cobbles and boulders; particularly machines that rely on screw conveyors for pressure control and muck transport.■ Steering difficulties and slower production may result from differences in material density between top and bottom of face (at interface between looser fill, denser native deposits and dense glacial till) and between each side of the machine; these differences will affect line and grade.■ Requires a work area at the entry shaft somewhat smaller than that needed for microtunnelling.	1.0 – 1.5	<ul style="list-style-type: none">■ Encountering woody debris and oversized cobble nests or boulders - moderate to high risk of not completing installation.■ Tunnel invert along interface between embankment fill and native materials - low to moderate risk of not achieving line and grade if machine deflected by hard/very dense soils.■ Groundwater at the tunnel invert - low risk of ground loss due to flowing of sands if closed-face machine selected.■ Moderate to high risk of ground losses in saturated granular soils when removing or mining through boulders or other obstructions if groundwater is not controlled by other means.



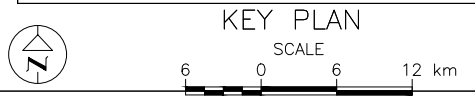
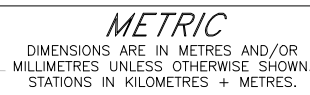
Table 2: Comparison of Trenchless Techniques for Culvert Replacement

1. The availability of contractors in Ontario with large-scale jack-and-bore or pipe ramming equipment and experience installing pipes with diameters of 1.8 m or greater is rare or non-existent. The typical maximum casing sizes are 1.8 m for jack-and-bore and 2.5 m for pipe ramming. Considering MTBMs currently manufactured, the maximum pipe size that can be installed is 4.2 m (outer diameter); however most Ontario microtunnelling contractors typically install a maximum diameter of 2.1m.
2. Costs are based on order of magnitude estimates in 2017 dollars derived from projects of generally similar scope and technologies. They are intended to provide a comparison between alternatives rather than actual construction costs, and exclude additional costs such as traffic control, staging and shoring that may influence the total cost. Therefore, the costs should be considered only for comparative purposes.
3. The estimated relative cost factor represents an approximately simplified cost estimate for each option divided by the estimated cost for the least expensive option (e.g., a relative cost factor of 2 indicates that the trenchless technology option is twice as costly as the least expensive option).








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DRAWINGS



LEGEND

	Borehole – Current Investigation
	Seal
	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
	WL in piezometer, measured on MAR. 28, 2017
	WL upon completion of drilling

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
C6-1	125.6	4866801.7	387804.4
C6-2	130.0	4866792.6	387845.2
C6-3	130.0	4866757.4	387833.9
C6-4	121.9	4866739.4	387857.0

NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed from geological evidence.

Geographic Coordinates of Culvert: Latitude 43.935910; Longitude -78.465670

REFERENCE

Base Plan and Contours provided in digital format by DM Wills, drawing file nos. 124234.dwg, received Jan. 20, 2016. Design Plan and Section provided in digital format by DM Wills, drawing file no. 4561-C6 GA.dwg, received Jan. 3, 2017.

NO.		DATE		BY		REVISION	
Geocres No. 30M15-312							
HWY. 401				PROJECT NO. 1540419		DIST. .	
SUBM'D. MCK		CHKD. MCK		DATE: 6/12/2017		SITE: 21-494/C	
DRAWN: SMD		CHKD. MWK		APPD. JMAC		DWG. 1	



APPENDIX A

Record of Boreholes



LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

I. GENERAL

π	3.1416
$\ln x$,	natural logarithm of x
\log_{10}	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta \sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
ν	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

$\rho(\gamma)$	bulk density (bulk unit weight)*
$\rho_d(\gamma_d)$	dry density (dry unit weight)
$\rho_w(\gamma_w)$	density (unit weight) of water
$\rho_s(\gamma_s)$	density (unit weight) of solid particles
γ'	unit weight of submerged soil ($\gamma' = \gamma - \gamma_w$)
D_R	relative density (specific gravity) of solid particles ($D_R = \rho_s / \rho_w$) (formerly G_s)
e	void ratio
n	porosity
S	degree of saturation

* Density symbol is ρ . Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density multiplied by acceleration due to gravity)

(a) Index Properties (continued)

w	water content
w_l or LL	liquid limit
w_p or PL	plastic limit
I_p or PI	plasticity index = $(w_l - w_p)$
w_s	shrinkage limit
I_L	liquidity index = $(w - w_p) / I_p$
I_C	consistency index = $(w_l - w) / I_p$
e_{max}	void ratio in loosest state
e_{min}	void ratio in densest state
I_D	density index = $(e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

(b) Hydraulic Properties

h	hydraulic head or potential
q	rate of flow
v	velocity of flow
i	hydraulic gradient
k	hydraulic conductivity (coefficient of permeability)
j	seepage force per unit volume

(c) Consolidation (one-dimensional)

C_c	compression index (normally consolidated range)
C_r	recompression index (over-consolidated range)
C_s	swelling index
C_{α}	secondary compression index
m_v	coefficient of volume change
C_v	coefficient of consolidation (vertical direction)
C_h	coefficient of consolidation (horizontal direction)
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation stress
OCR	over-consolidation ratio = σ'_p / σ'_{vo}

(d) Shear Strength

τ_p, τ_r	peak and residual shear strength
ϕ'	effective angle of internal friction
δ	angle of interface friction
μ	coefficient of friction = $\tan \delta$
c'	effective cohesion
c_u, s_u	undrained shear strength ($\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p'	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 - \sigma_3)$
S_t	sensitivity

Notes: 1
2

$\tau = c' + \sigma' \tan \phi'$
shear strength = (compressive strength)/2



LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split-spoon
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:

The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) drive open sampler for a distance of 300 mm (12 in.)

Dynamic Cone Penetration Resistance; N_d :

The number of blows by a 63.5 kg (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

PH: Sampler advanced by hydraulic pressure

PM: Sampler advanced by manual pressure

WH: Sampler advanced by static weight of hammer

WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm² pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (Q_t), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

III. SOIL DESCRIPTION

(a) Non-Cohesive Soils

Density Index	N
Relative Density	Blows/300 mm or Blows/ft
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

(b) Cohesive Soils Consistency

	C_u, S_u	
	kPa	psf
Very soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1,000
Stiff	50 to 100	1,000 to 2,000
Very stiff	100 to 200	2,000 to 4,000
Hard	over 200	over 4,000


IV. SOIL TESTS

w	water content
w _p	plastic limit
w _l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test ¹
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement ¹
D _R	relative density (specific gravity, G_s)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO ₄	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

Note: 1 Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.

V. MINOR SOIL CONSTITUENTS

Per cent by Weight	Modifier	Example
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand

PROJECT 1540419		RECORD OF BOREHOLE No C6-1		SHEET 1 OF 2		METRIC															
G.W.P. 2242-14-00		LOCATION N 4866801.7; E 387804.4 MTM ZONE 10 (LAT. 43.936526; LONG. -78.466115)		ORIGINATED BY AJ																	
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 127 mm Dia. Solid Stem Augers (Automatic Hammer)		COMPILED BY SZ																	
DATUM Geodetic		DATE October 5, 2016		CHECKED BY MWK																	
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT			REMARKS & GRAIN SIZE DISTRIBUTION (%)						
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa					WATER CONTENT (%)			γ			GR SA SI CL		
125.6	GROUND SURFACE							20 40 60 80 100 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED					W _p — W — W _L 10 20 30			kN/m ³					
0.0	Sandy silt, trace clay, trace gravel (FILL) Compact Brown Moist		1	SS	10		125														
124.9	Gravelly silt and sand, trace to some clay (FILL) Compact to very dense Brown Moist		2	SS	13		124														
0.7	- Auger grinding between depths of 1.2 m and 1.5 m below ground surface (Elev. 124.4 m and 124.1 m)		3	SS	58		123														
123.5	SILT and SAND, trace to some gravel, trace to some clay (TILL) Very dense Brown to grey Moist		4	SS	72		122														
2.1	- Auger grinding at a depth of 3.4 m below ground surface (Elev. 122.2 m)		5	SS	52/0.10		121														
	- Becoming wet below a depth of 4.6 m below ground surface (Elev. 121.0 m)		6	SS	50/0.08		120														
			7	SS	50/0.15		119														
	- Auger grinding at a depth of 6.4 m below ground surface (Elev. 119.2 m)		8	SS	58/0.13		118														
			9	SS	57/0.15		117														
			10	SS	50/0.08		116														
			11	SS	55/0.10		115														
114.2	CLAYEY SILT, trace sand (TILL) Hard Grey Moist						114														
11.4						113															
111.8	END OF BOREHOLE					112															
13.8																					

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

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+³, ×³: Numbers refer to Sensitivity ○^{3%} STRAIN AT FAILURE

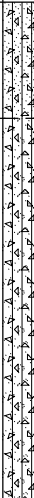
PROJECT <u>1540419</u>		RECORD OF BOREHOLE No C6-2		SHEET 1 OF 2		METRIC	
G.W.P. <u>2242-14-00</u>		LOCATION <u>N 4866792.6; E 387845.2 MTM ZONE 10 (LAT. 43.936431; LONG. -78.465606)</u>		ORIGINATED BY <u>AJ</u>			
DIST <u> </u> HWY <u>401</u>		BOREHOLE TYPE <u>CME 75, 127 mm Dia. Solid Stem Augers (Automatic Hammer)</u>		COMPILED BY <u>SZ</u>			
DATUM <u>Geodetic</u>		DATE <u>October 6, 2016</u>		CHECKED BY <u>MWK</u>			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)							
								20	40	60	80	100	W _p	W	W _L					
130.0	GROUND SURFACE																			
0.0	ASPHALT																			
129.5																				
0.5	Sand and gravel, trace silt (FILL) Very dense Brown Moist		1	SS	60															
128.7																				
1.3	Silt and sand, trace to some gravel, trace to some clay (FILL) Dense Brown Moist		2	SS	45															
			3	SS	42															
			4	SS	31															
			5	SS	48															
124.7																				
5.3	Silty sand, trace gravel, trace clay, trace organics (FILL) Compact Grey to brown Moist		6	SS	27															
122.1			7A	SS	13															
7.9	SILT, some sand, trace organics (rootlets) Compact Brown Moist		7B																	
121.6																				
8.4	Sandy SILT, trace to some clay, trace gravel (TILL) Very dense Grey Moist		8	SS	52/0.15															
			9	SS	55/0.13															
			10	SS	55/0.13															

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+ ³, × ³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

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PROJECT 1540419		RECORD OF BOREHOLE No C6-2				SHEET 2 OF 2		METRIC									
G.W.P. 2242-14-00		LOCATION N 4866792.6; E 387845.2 MTM ZONE 10 (LAT. 43.936431; LONG. -78.465606)				ORIGINATED BY AJ											
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 127 mm Dia. Solid Stem Augers (Automatic Hammer)				COMPILED BY SZ											
DATUM Geodetic		DATE October 6, 2016				CHECKED BY MWK											
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa									WATER CONTENT (%)
	--- CONTINUED FROM PREVIOUS PAGE ---																
113.9	SILT, trace to some sand, trace to some clay (TILL) Very dense Grey Wet		12	SS	90/0.25												
16.2	Sandy SILT, trace to some gravel, some clay (TILL) Very dense Grey Wet		13	SS	56/0.15												
			14	SS	50/0.18												
			15	SS	50/0.13												
110.1	END OF BOREHOLE NOTE: 1. Water level in open borehole at a depth of 10.7 m below ground surface (Elev. 119.3 m) upon completion of drilling.																
19.9																	

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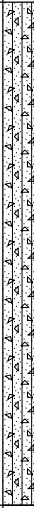


PROJECT 1540419		RECORD OF BOREHOLE No C6-3		SHEET 1 OF 2		METRIC	
G.W.P. 2242-14-00		LOCATION N 4866757.4; E 387833.9 MTM ZONE 10 (LAT. 43.936124; LONG. -78.465756)		ORIGINATED BY		AJ	
DIST HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 108 mm I.D. Hollow Stem Augers (Automatic Hammer)		COMPILED BY		SZ	
DATUM Geodetic		DATE December 1, 2016		CHECKED BY		MWK	

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+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

PROJECT 1540419		RECORD OF BOREHOLE No C6-3				SHEET 2 OF 2		METRIC									
G.W.P. 2242-14-00		LOCATION N 4866757.4; E 387833.9 MTM ZONE 10 (LAT. 43.936124; LONG. -78.465756)				ORIGINATED BY AJ											
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 108 mm I.D. Hollow Stem Augers (Automatic Hammer)				COMPILED BY SZ											
DATUM Geodetic		DATE December 1, 2016				CHECKED BY MWK											
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa									
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED									
	--- CONTINUED FROM PREVIOUS PAGE ---						20	40	60	80	100						
	SILT, some sand, trace gravel, some clay (TILL) Hard Grey Wet		13	SS	65/0.15												
			14	SS	60/0.18												
			15	SS	55/0.13												
			16	SS	57/0.18												
110.0	END OF BOREHOLE																
20.0	NOTE: 1. Water level not established.																

PROJECT 1540419		RECORD OF BOREHOLE No C6-4		SHEET 1 OF 1		METRIC							
G.W.P. 2242-14-00		LOCATION N 4866739.4; E 387857.0 MTM ZONE 10 (LAT. 43.935959; LONG. -78.465471)		ORIGINATED BY AJ/IK									
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 178 mm O.D., 108 mm I.D. Hollow Stem Augers (Automatic Hammer)		COMPILED BY SZ									
DATUM Geodetic		DATE October 3 and 4, 2016		CHECKED BY MWK									
SOIL PROFILE			SAMPLES		GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa		WATER CONTENT (%)			
121.9	GROUND SURFACE						20 40 60 80 100	20 40 60 80 100	10 20 30				
0.9	TOPSOIL		1A	SS	3								
121.2	Clayey silt, some sand, trace gravel, trace organics (FILL) Soft Grey Moist		1B	SS	3								
0.7			2	SS	3								
120.1	Sandy silt, some clay, trace gravel, trace organics (rootlets) (FILL) Very loose Brown Wet		3A										
1.8	- Auger grinding at a depth of 1.5 m below ground surface (Elev. 120.4 m)		3B	SS	13								
	SILT, some clay, trace to some sand Compact to very dense Grey Moist		4	SS	89								
			5	SS	105								
117.9													
4.0	Sandy SILT to SILT and SAND, trace to some gravel, trace to some clay (TILL) Very dense Grey Dry to moist		6	SS	58/0.13								
			7	SS	53/0.13								
	- Auger grinding between depths of 6.7 m and 7.0 m below ground surface (Elev. 115.2 m and 114.9 m)		8	SS	50/0.08								
			9	SS	50/0.10								
	- Auger grinding at a depth of 9.4 m below ground surface (Elev. 112.5 m)												
111.1													
10.8	END OF BOREHOLE		10	SS	58/0.15								
NOTES: 1. Borehole caved to a depth of 8.2 m below ground surface. 2. Well installed 0.6 m west of Borehole C6-4. 3. Water level measured in piezometer: Date Depth(m) Elev.(m) 04/10/16 3.6 118.3 28/03/17 -0.1 122.0													

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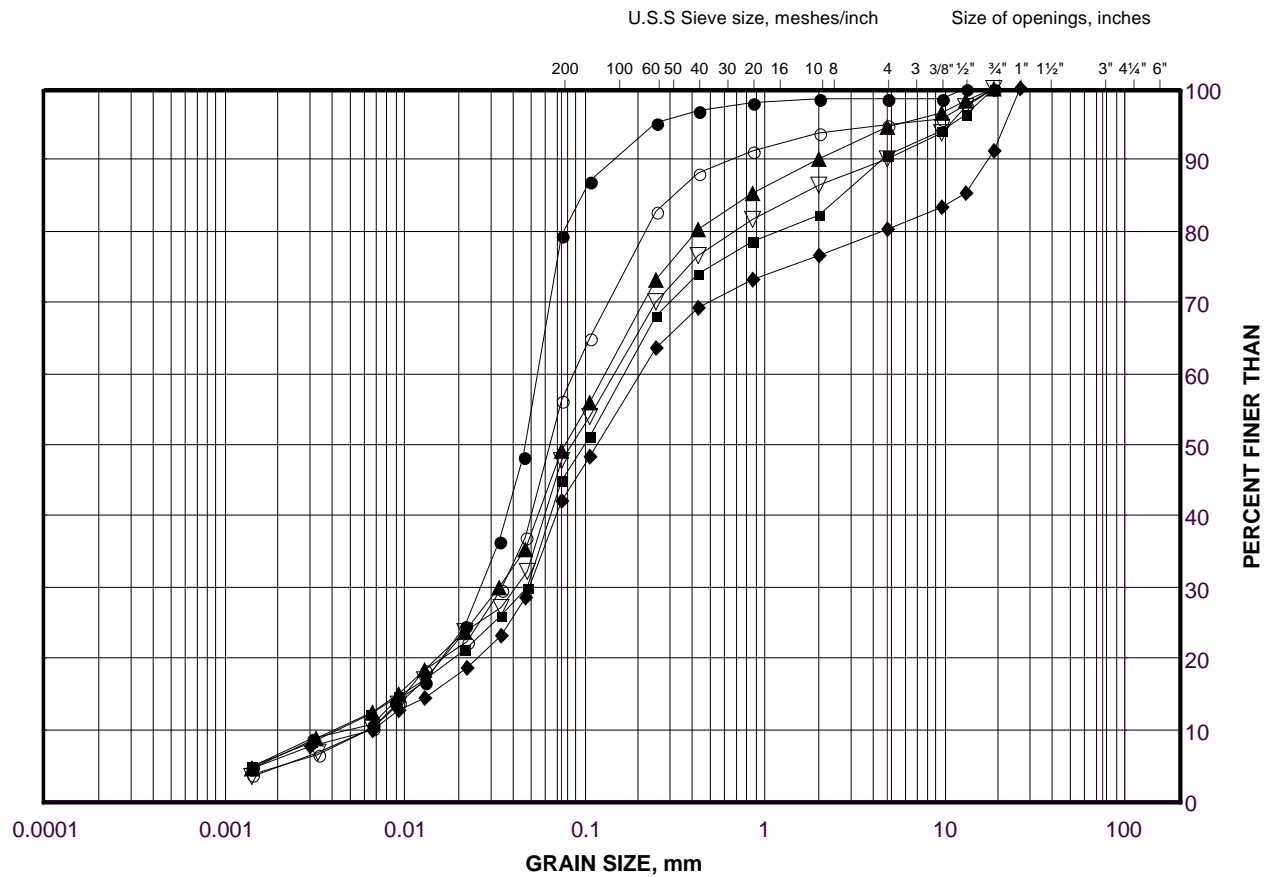
APPENDIX B

Laboratory Results

GRAIN SIZE DISTRIBUTION

Sandy Silt to Silt and Sand (Fill)

FIGURE B1



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C6-4	2	120.9
■	C6-2	3	127.5
◆	C6-1	3	123.8
▲	C6-2	5	125.2
▽	C6-3	6	125.1
○	C6-3	8	122.0

Project Number: 1540419

Checked By: MWK

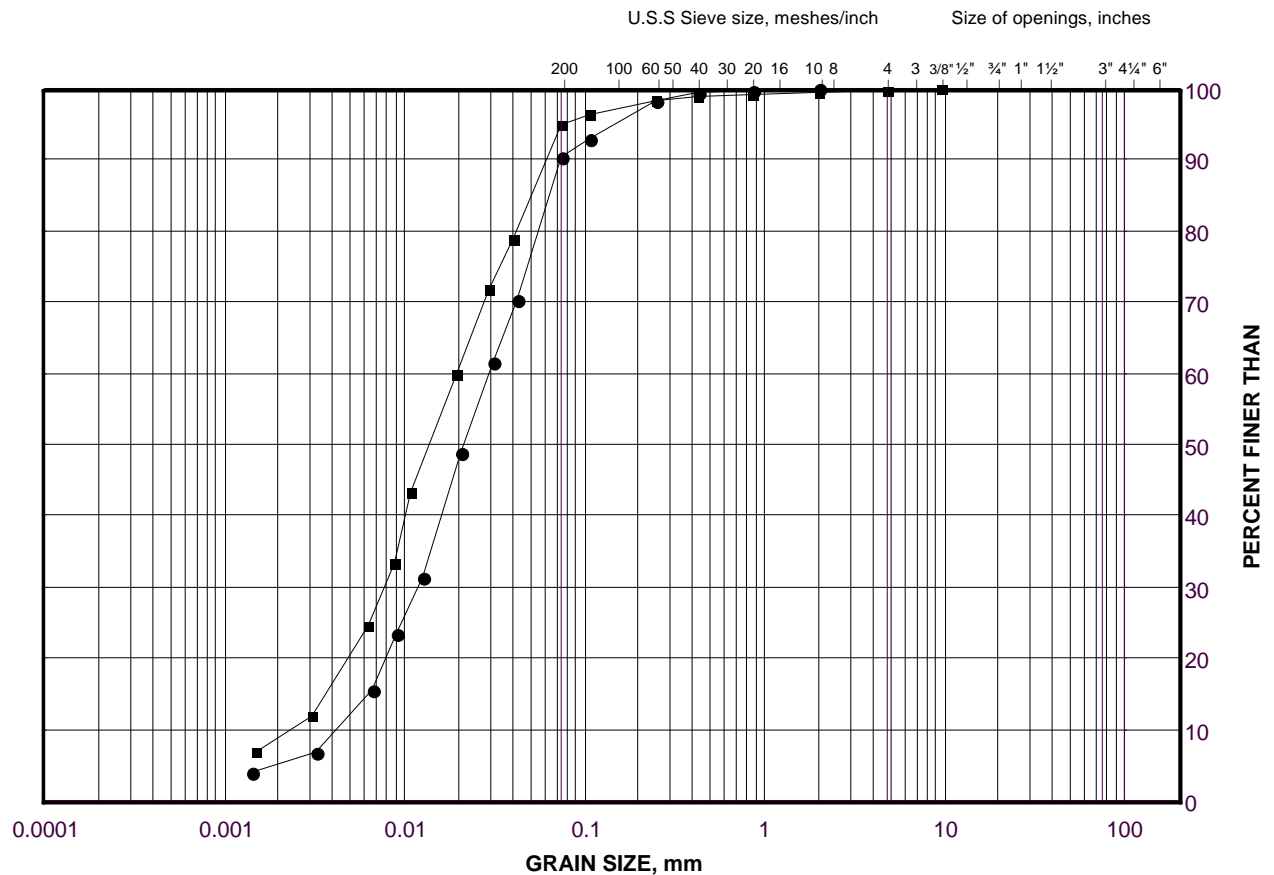
Golder Associates

Date: 31-Jan-17

GRAIN SIZE DISTRIBUTION

Silt

FIGURE B2



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●	C6-3	10	119.1
■	C6-4	4	119.4

Project Number: 1540419

Checked By: MWK

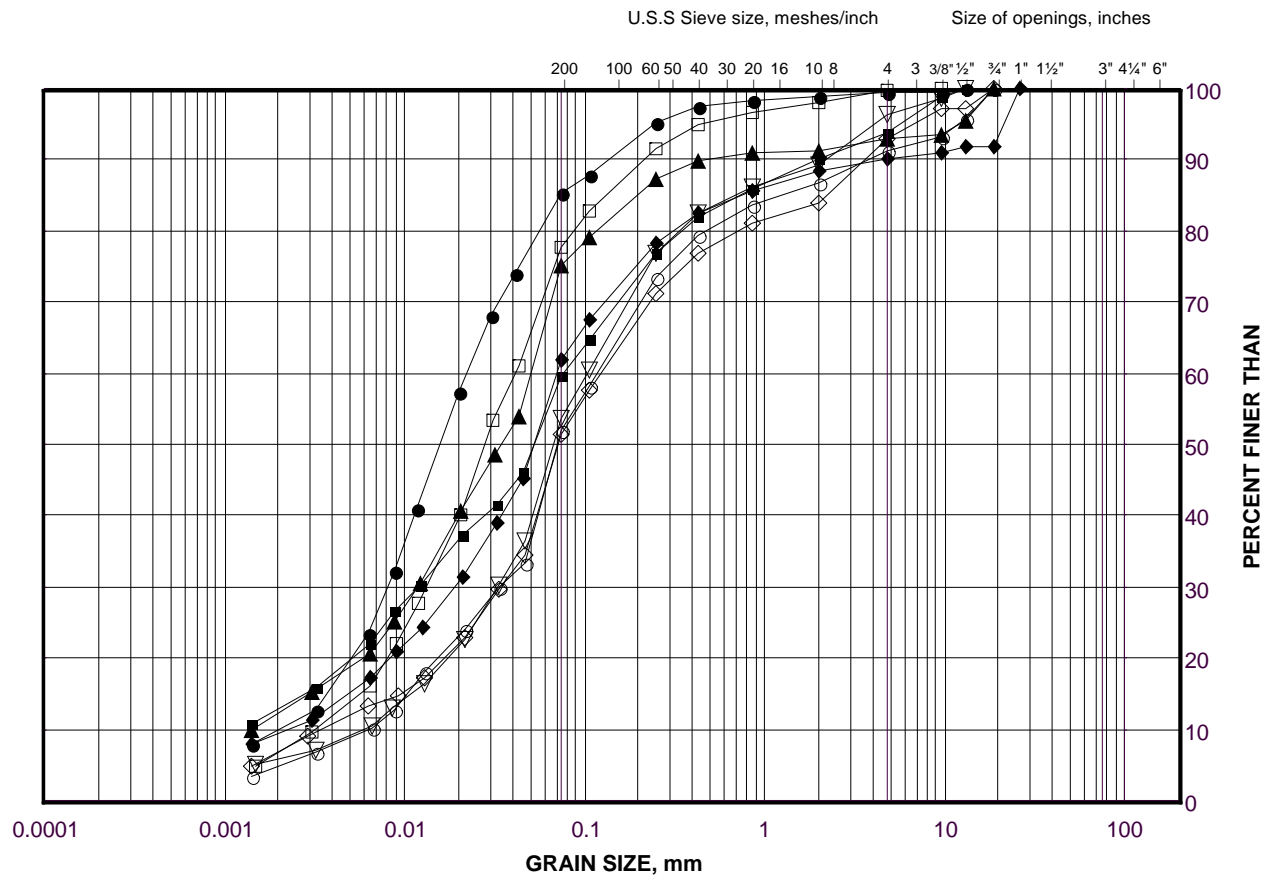
Golder Associates

Date: 31-Jan-17

GRAIN SIZE DISTRIBUTION

Sandy Silt to Silt and Sand (Till)

FIGURE B3



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●	C6-2	11	116.2
■	C6-3	12	116.2
◆	C6-2	14	111.6
□	C6-4	6	117.2
•	C6-1	6	120.9
○	C6-1	8	117.9
□	C6-2	9	119.2
□	C6-4	9	112.8

Project Number: 1540419

Checked By: MWK

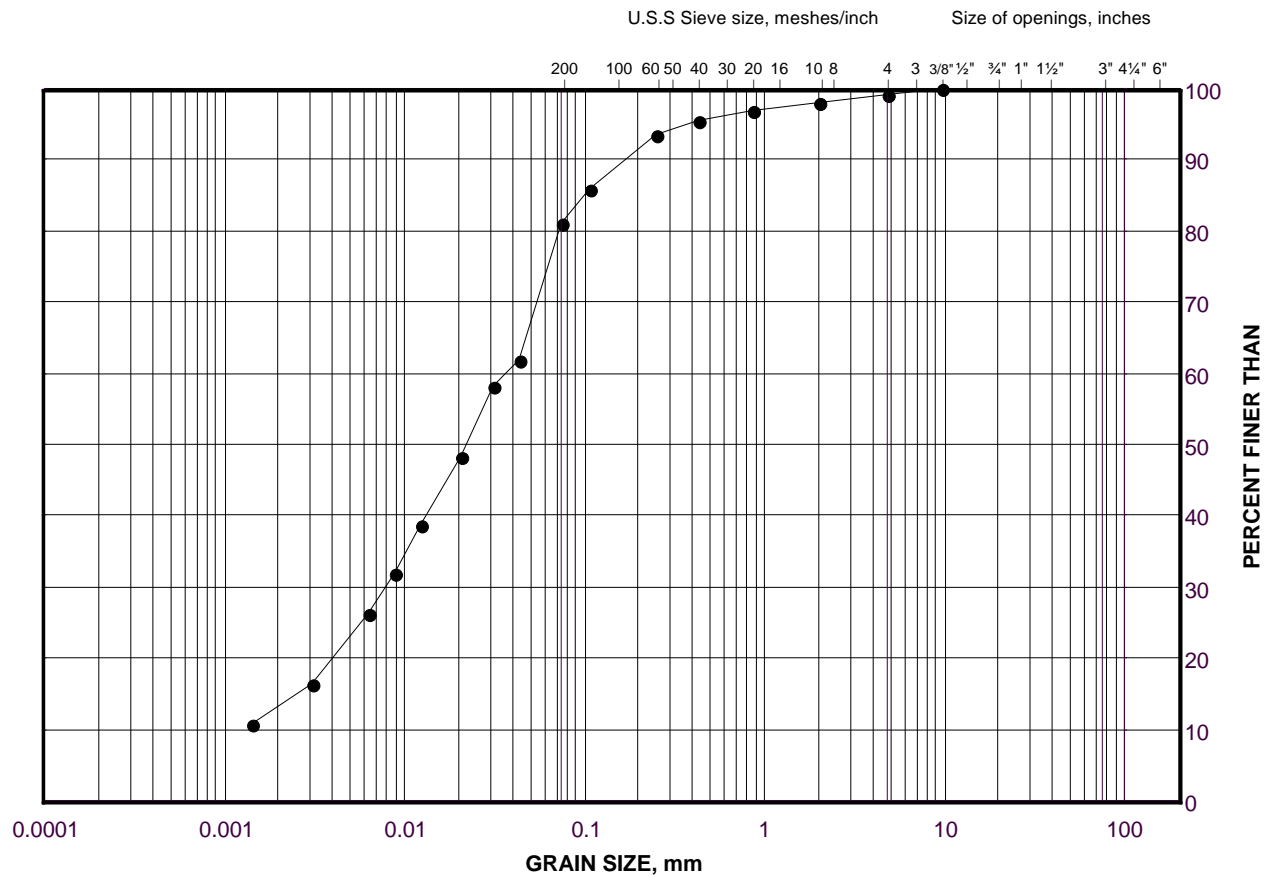
Golder Associates

Date: 02-Feb-17

GRAIN SIZE DISTRIBUTION

Silt (Till)

FIGURE B4



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

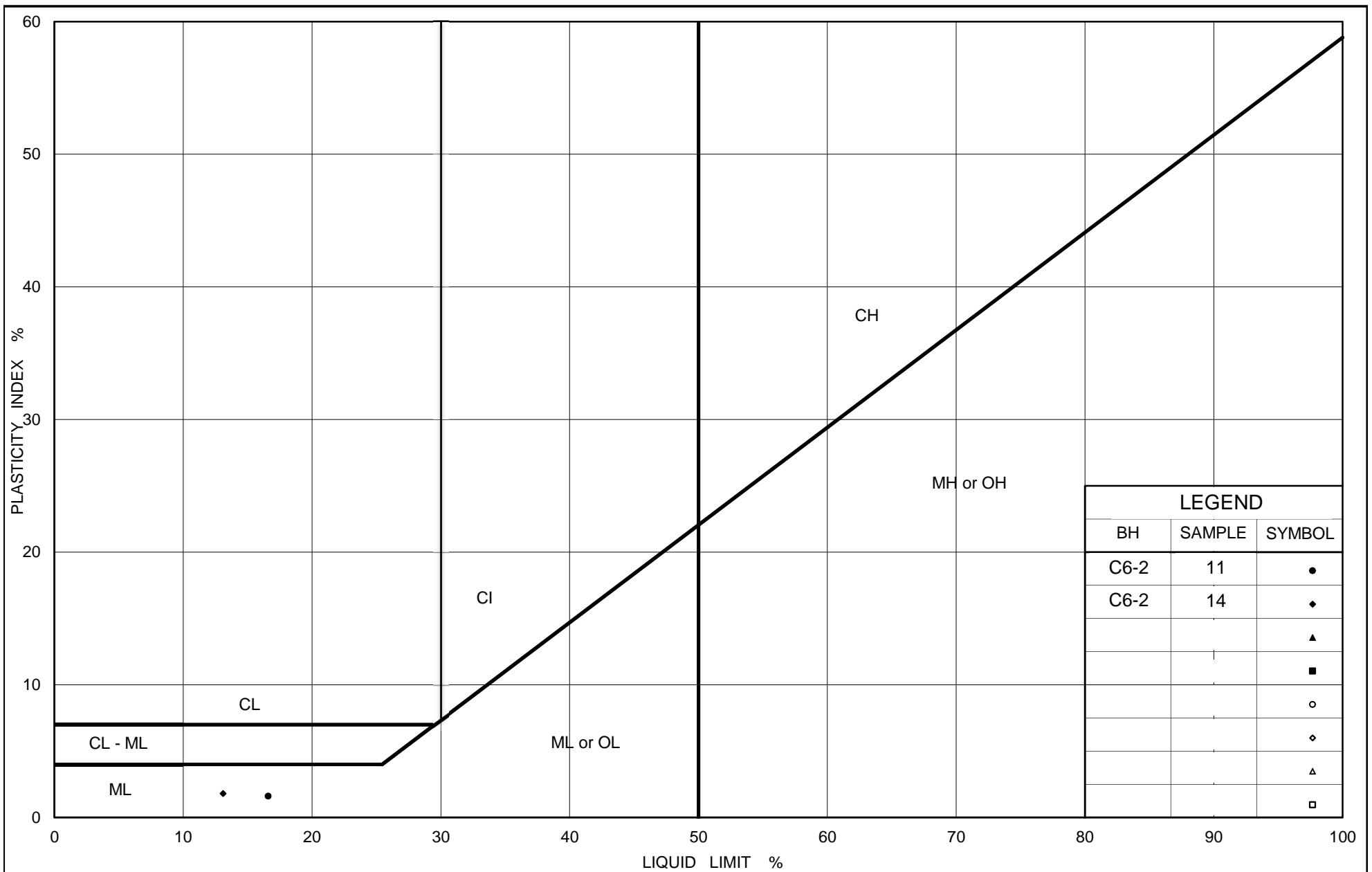
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	C6-3	14	113.1

Project Number: 1540419

Checked By: MWK

Golder Associates

Date: 02-Feb-17

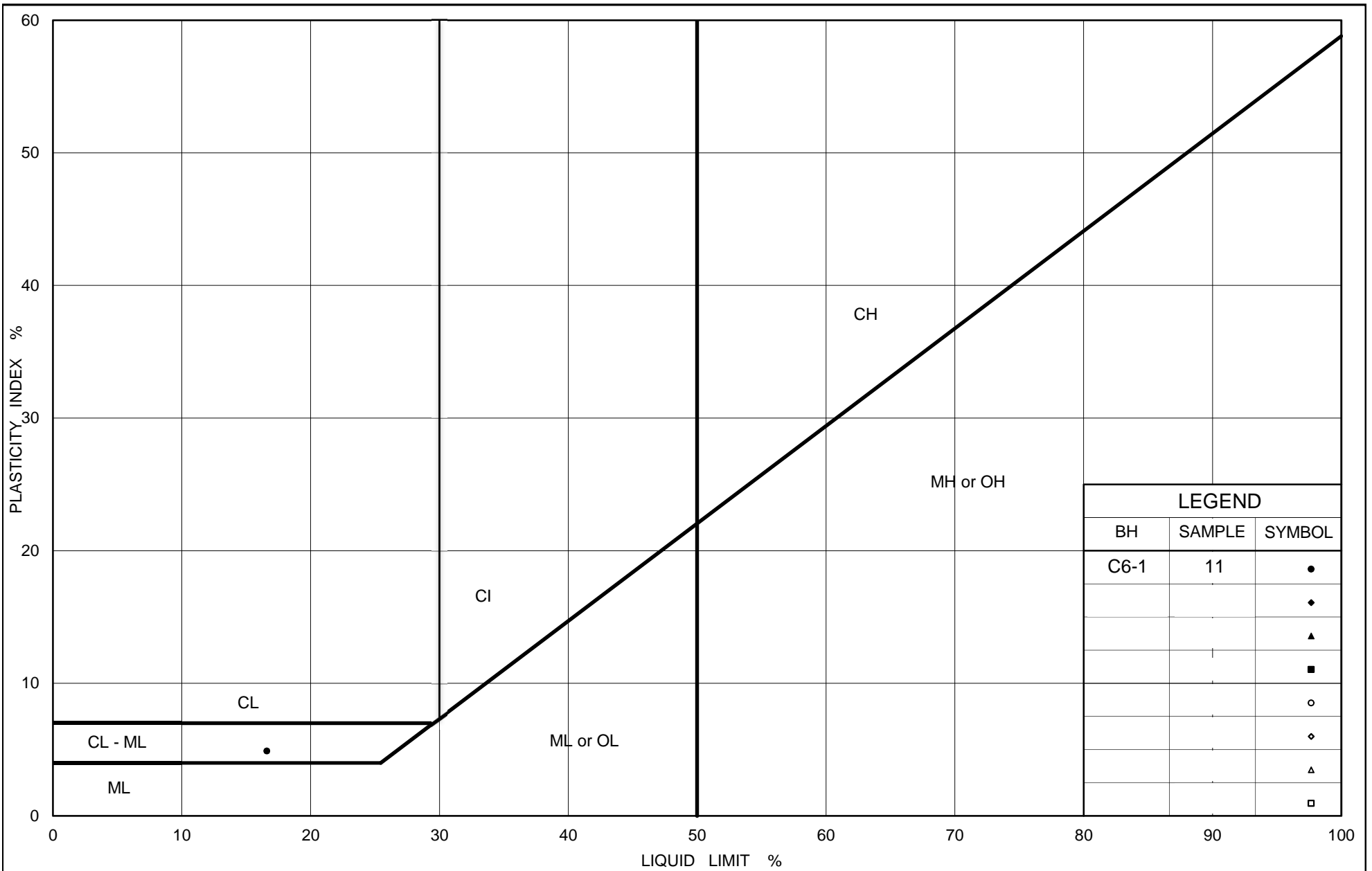


PLASTICITY CHART Silt (Till)

Figure No. B5

Project No. 1540419

Checked By: MWK



PLASTICITY CHART Clayey Silt (Till)

Figure No. B6

Project No. 1540419

Checked By: MWK



APPENDIX C

Analytical Test Results

Your Project #: 1540419
Your C.O.C. #: 573330-02-01

Attention: Matt Kelly

Golder Associates Ltd
Mississauga - Standing Offer
6925 Century Ave
Suite 100
Mississauga, ON
CANADA L5N 7K2

Report Date: 2016/12/22
Report #: R4298821
Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B6R4426

Received: 2016/12/16, 15:25

Sample Matrix: Soil
Samples Received: 3

Analyses	Date		Date Analyzed	Laboratory Method	Reference
	Quantity	Extracted			
Chloride (20:1 extract)	3	N/A	2016/12/21	CAM SOP-00463	EPA 325.2 m
Conductivity	3	N/A	2016/12/21	CAM SOP-00414	OMOE E3530 v1 m
pH CaCl2 EXTRACT	3	2016/12/20	2016/12/20	CAM SOP-00413	EPA 9045 D m
Resistivity of Soil	3	2016/12/16	2016/12/22	CAM SOP-00414	SM 22 2510 m
Sulphate (20:1 Extract)	3	N/A	2016/12/21	CAM SOP-00464	EPA 375.4 m

Remarks:

Maxxam Analytics' laboratories are accredited to ISO/IEC 17025:2005 for specific parameters on scopes of accreditation. Unless otherwise noted, procedures used by Maxxam are based upon recognized Provincial, Federal or US method compendia such as CCME, MDDELCC, EPA, APHA.

All work recorded herein has been done in accordance with procedures and practices ordinarily exercised by professionals in Maxxam's profession using accepted testing methodologies, quality assurance and quality control procedures (except where otherwise agreed by the client and Maxxam in writing). All data is in statistical control and has met quality control and method performance criteria unless otherwise noted. All method blanks are reported: unless indicated otherwise, associated sample data are not blank corrected.

Maxxam Analytics' liability is limited to the actual cost of the requested analyses, unless otherwise agreed in writing. There is no other warranty expressed or implied. Maxxam has been retained to provide analysis of samples provided by the Client using the testing methodology referenced in this report. Interpretation and use of test results are the sole responsibility of the Client and are not within the scope of services provided by Maxxam, unless otherwise agreed in writing.

Solid sample results, except biota, are based on dry weight unless otherwise indicated. Organic analyses are not recovery corrected except for isotope dilution methods. Results relate to samples tested.

This Certificate shall not be reproduced except in full, without the written approval of the laboratory.

Reference Method suffix "m" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

Your Project #: 1540419
Your C.O.C. #: 573330-02-01

Attention:Matt Kelly

Golder Associates Ltd
Mississauga - Standing Offer
6925 Century Ave
Suite 100
Mississauga, ON
CANADA L5N 7K2

Report Date: 2016/12/22
Report #: R4298821
Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B6R4426
Received: 2016/12/16, 15:25

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

Ema Gitej, Senior Project Manager

Email: EGitej@maxxam.ca

Phone# (905)817-5829

=====

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

RESULTS OF ANALYSES OF SOIL

Maxxam ID		DQK405	DQK406	DQK407		
Sampling Date		2016/11/27 04:00	2016/12/01 22:00	2016/12/06 03:00		
COC Number		573330-02-01	573330-02-01	573330-02-01		
	UNITS	C5	C6	C7	RDL	QC Batch
Calculated Parameters						
Resistivity	ohm-cm	1100	1200	2100		4796272
Inorganics						
Soluble (20:1) Chloride (Cl)	ug/g	340	450	180	20	4799839
Conductivity	umho/cm	889	824	467	2	4800256
Available (CaCl2) pH	pH	7.69	7.95	7.86		4798509
Soluble (20:1) Sulphate (SO4)	ug/g	240	23	49	20	4799840
RDL = Reportable Detection Limit						
QC Batch = Quality Control Batch						

TEST SUMMARY

Maxxam ID: DQK405
Sample ID: C5
Matrix: Soil

Collected: 2016/11/27
Shipped:
Received: 2016/12/16

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4799839	N/A	2016/12/21	Deonarine Ramnarine
Conductivity	AT	4800256	N/A	2016/12/21	Tahir Anwar
pH CaCl2 EXTRACT	AT	4798509	2016/12/20	2016/12/20	Surinder Rai
Resistivity of Soil		4796272	2016/12/22	2016/12/22	Cristina Carriere
Sulphate (20:1 Extract)	KONE/EC	4799840	N/A	2016/12/21	Deonarine Ramnarine

Maxxam ID: DQK406
Sample ID: C6
Matrix: Soil

Collected: 2016/12/01
Shipped:
Received: 2016/12/16

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4799839	N/A	2016/12/21	Deonarine Ramnarine
Conductivity	AT	4800256	N/A	2016/12/21	Tahir Anwar
pH CaCl2 EXTRACT	AT	4798509	2016/12/20	2016/12/20	Surinder Rai
Resistivity of Soil		4796272	2016/12/22	2016/12/22	Cristina Carriere
Sulphate (20:1 Extract)	KONE/EC	4799840	N/A	2016/12/21	Deonarine Ramnarine

Maxxam ID: DQK407
Sample ID: C7
Matrix: Soil

Collected: 2016/12/06
Shipped:
Received: 2016/12/16

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4799839	N/A	2016/12/21	Deonarine Ramnarine
Conductivity	AT	4800256	N/A	2016/12/21	Tahir Anwar
pH CaCl2 EXTRACT	AT	4798509	2016/12/20	2016/12/20	Surinder Rai
Resistivity of Soil		4796272	2016/12/22	2016/12/22	Cristina Carriere
Sulphate (20:1 Extract)	KONE/EC	4799840	N/A	2016/12/21	Deonarine Ramnarine

GENERAL COMMENTS

Each temperature is the average of up to three cooler temperatures taken at receipt

Package 1	5.7°C
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Results relate only to the items tested.

QUALITY ASSURANCE REPORT

QC Batch	Parameter	Date	Matrix Spike		SPIKED BLANK		Method Blank		RPD	
			% Recovery	QC Limits	% Recovery	QC Limits	Value	UNITS	Value (%)	QC Limits
4798509	Available (CaCl ₂) pH	2016/12/20			98	97 - 103			1.4	N/A
4799839	Soluble (20:1) Chloride (Cl)	2016/12/21	115	70 - 130	106	70 - 130	<20	ug/g	NC	35
4799840	Soluble (20:1) Sulphate (SO ₄)	2016/12/21	NC	70 - 130	106	70 - 130	<20	ug/g	NC	35
4800256	Conductivity	2016/12/21			100	90 - 110	<2	umho/cm	1.6	10

N/A = Not Applicable

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.

Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.

Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

NC (Matrix Spike): The recovery in the matrix spike was not calculated. The relative difference between the concentration in the parent sample and the spiked amount was too small to permit a reliable recovery calculation (matrix spike concentration was less than 2x that of the native sample concentration).

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (one or both samples < 5x RDL).

VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Cristina Carriere

Cristina Carriere, Scientific Services

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.



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CHAIN OF CUSTODY RECORD

Page 1 of 1

INVOICE TO:		REPORT TO:		PROJECT INFORMATION:		Laboratory Use Only:																													
Company Name: #1326 Golder Associates Ltd		Company Name: Matt Kelly ; Madison Kennedy		Quotation #: B63104		Maxxam Job #:																													
Attention: Central Acct: 1112, 1113, 1118		Attention: Matt Kelly ; Madison Kennedy		P.O. #: 1540419		Bottle Order #:																													
Address: 6925 Century Ave Suite 100		Address:		Project: 1540419		COC #:																													
Mississauga ON L5N 7K2				Project Name:		Project Manager: Ema Gitej																													
Tel: (905) 567-4444 Fax: (905) 567-6561		Tel: Matthew_Kelly@golder.com ; MadKennedy@golder.ca		Site #:		C#573330-02-01																													
Email: Catherine_Guiao@golder.com, Rachel_Benjamin@golder.com		Email:		Sampled By:		Turnaround Time (TAT) Required: Please provide advance notice for rush projects																													
MOE REGULATED DRINKING WATER OR WATER INTENDED FOR HUMAN CONSUMPTION MUST BE SUBMITTED ON THE MAXXAM DRINKING WATER CHAIN OF CUSTODY				ANALYSIS REQUESTED (PLEASE BE SPECIFIC)																															
<table border="1"><thead><tr><th colspan="2">Regulation 153 (2011)</th><th colspan="2">Other Regulations</th><th colspan="2">Special Instructions</th></tr></thead><tbody><tr><td><input type="checkbox"/> Table 1</td><td><input type="checkbox"/> Res/Park</td><td><input type="checkbox"/> CCME</td><td><input type="checkbox"/> Sanitary Sewer Bylaw</td><td colspan="2" rowspan="5"></td></tr><tr><td><input type="checkbox"/> Table 2</td><td><input type="checkbox"/> Ind/Comm</td><td><input type="checkbox"/> Reg 558</td><td><input type="checkbox"/> Storm Sewer Bylaw</td></tr><tr><td><input type="checkbox"/> Table 3</td><td><input type="checkbox"/> Agri/Other</td><td><input type="checkbox"/> MISA</td><td><input type="checkbox"/> Municipality</td></tr><tr><td><input type="checkbox"/> Table</td><td><input type="checkbox"/> For RSC</td><td><input type="checkbox"/> PWQO</td><td></td></tr><tr><td></td><td></td><td><input type="checkbox"/> Other</td><td></td></tr></tbody></table>				Regulation 153 (2011)		Other Regulations		Special Instructions		<input type="checkbox"/> Table 1	<input type="checkbox"/> Res/Park	<input type="checkbox"/> CCME	<input type="checkbox"/> Sanitary Sewer Bylaw			<input type="checkbox"/> Table 2	<input type="checkbox"/> Ind/Comm	<input type="checkbox"/> Reg 558	<input type="checkbox"/> Storm Sewer Bylaw	<input type="checkbox"/> Table 3	<input type="checkbox"/> Agri/Other	<input type="checkbox"/> MISA	<input type="checkbox"/> Municipality	<input type="checkbox"/> Table	<input type="checkbox"/> For RSC	<input type="checkbox"/> PWQO				<input type="checkbox"/> Other		Field Filled (please circle): Metals / Hg / Cr-VI Conductivity (µS/cm) / SO4 EC Resistivity (µS/cm)			
Regulation 153 (2011)		Other Regulations		Special Instructions																															
<input type="checkbox"/> Table 1	<input type="checkbox"/> Res/Park	<input type="checkbox"/> CCME	<input type="checkbox"/> Sanitary Sewer Bylaw																																
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<input type="checkbox"/> Table	<input type="checkbox"/> For RSC	<input type="checkbox"/> PWQO																																	
		<input type="checkbox"/> Other																																	
Include Criteria on Certificate of Analysis (Y/N)?																																			
Sample Barcode Label	Sample (Location) Identification	Date Sampled	Time Sampled	Matrix																															
1	C5	2016/11/27	4:00 am	Soil	X																														
2	C6	2016/12/01	10:00 pm	Soil	X																														
3	C7	2016/12/06	3:00 am	Soil	X																														
4																																			
5																																			
6																																			
7																																			
8																																			
9																																			
10																																			
* RELINQUISHED BY: (Signature/Print)				RECEIVED BY: (Signature/Print)		Date: (YY/MM/DD)		Time		# Jars used and not submitted		Laboratory Use Only																							
Amelia Jensen				Tami Rasmussen		2016/12/10		15:25				Time Sensitive																							
												Temperature (°C) on Receipt																							
												6/1/6																							
												Custody Seal																							
												Present																							
												Intact																							
												Yes																							
												No																							
												White: Maxxam Yellow: Client																							

* IT IS THE RESPONSIBILITY OF THE RELINQUISHER TO ENSURE THE ACCURACY OF THE CHAIN OF CUSTODY RECORD. AN INCOMPLETE CHAIN OF CUSTODY MAY RESULT IN ANALYTICAL TAT DELAYS.

SAMPLES MUST BE KEPT COOL (< 10°C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM

White: Maxxam Yellow: Client

Maxxam Analytics International Corporation o/a Maxxam Analytics

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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